critic of his own and other people's experiments. He had the infinite capacity for taking pains, and an intuition for devising just the right experiment. If an analogy suggested itself no use was ever made of it until it had been submitted to experimental verification; but facts fell upon his mind like seeds on a fertile ground. He had a wonderful faculty for discerning the relative importance of them. He was fond of saying that: "In the fields of observation, chance only favours the mind which is prepared."

Then, too, he had the magnetism which made others love to work with him and follow his inspirations; he did so much that if it had not been for helpers much must have been left undone. He was a genius, a seer and a prophet, always adding to knowledge, always looking forward to more additions. "Science," he said, "has no nationality, because knowledge is the patrimony of humanity, the torch which gives light to the world. Science should be the highest personification of nationality because, of all nations, that one will always be foremost which shall be first to progress by the labours of thought and of intelligence."

Surely what I have said shows that the immortal Pasteur was one of the greatest solvers of nature's secrets the world has ever known, and that the debt owed to him by humanity is unpayable and incalculable.

Pasteur as Chemist.

By Professor T. M. Lowry, F.R.S.

In the brief time at my disposal I shall attempt only two things: first, to present in outline a picture of the work which won for Pasteur the chemist a place in the ranks of the Immortals; second, to indicate the bridge by which his chemical work is linked to those biological researches which enabled a mere chemist to claim the attention of a society such as that which I have the honour to address. My task has been made easy by Pasteur himself, since rather more than sixty years ago he delivered to the Chemical Society of Paris two lectures which cover precisely the same field as that into which I propose to guide you to-night.

Pasteur claimed that in his work on tartaric acid he was following in the footsteps of three physicists—Malus, Arago, and Biot. Malus, in 1808, had announced the discovery of the polarization of light by reflection—that is to say, that light reflected from a sheet of glass was altered in such a way that the vibrations in one plane entered the glass, whilst the vibrations in the perpendicular plane were reflected from it. The plane which contained the incident and reflected ray was described as the *plane of polarization.* Arago, in 1811, discovered that when a ray of polarized light was passed through a plate of quartz the plane of polarization was distorted, giving rise to beautiful chromatic effects. Biot, in 1812, made the further discovery that this distortion took the form of a uniform rotation of the plane of polarization, but that some plates of quartz rotated this plane to the right and others to the left. He also discovered, in 1815, that a similar rotation of the plane of polarization was produced by many natural products, such as oil of turpentine and solutions of sugar, of camphor, or of tartaric acid.

We now pass on to consider the relation between the geometrical form of the crystal and its ability to rotate the plane of polarized light. A typical crystal of quartz consists of a hexagonal prism capped by hexagonal pyramids. Haüy, however, detected the presence of tiny facets on the alternate corners, which made the crystals lopsided or asymmetric; he also found that these hemihedral facets could be distributed in two ways, giving rise to crystals which could not be superposed upon one another, although they could be converted into one another by reflection in a mirror. Quartz crystals could, therefore, assume two different geometrical forms, whilst plates of quartz could rotate the plane of polarization of light in two opposite ways. It was left to Sir John Herschel, in 1820, to discover the correlation between these facts, and to show that crystals having one geometrical form always rotated the plane of polarization to the right, whilst those of opposite form rotated it to the left.

I now pass on to consider Pasteur's discovery of similar phenomena in tartaric acid. This acid was known in two forms—the ordinary dextro-tartaric acid, which rotated the plane of polarization to the right, and a modification (which Pasteur called *para*-tartaric acid), which possessed identical chemical

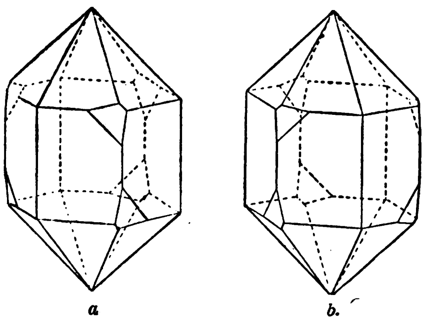
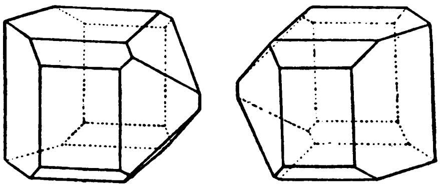


FIG. 1.—(*a*) Dextro-rotatory quartz ; (*b*) Lævo-rotatory quartz.

properties, but was devoid of optical rotatory power. Pasteur found that tartaric acid and its salts all gave asymmetric crystals, like quartz, whilst the *para*-tartrates gave symmetrical crystals. It appeared, therefore, that there might exist a correlation between the asymmetric crystals of the tartrates and the optical rotatory power of their solutions, similar to that which existed between the asymmetric crystals of quartz and the optical activity of solid plates cut from the crystal.

At this stage Pasteur's attention became fixed upon an observation of Mitscherlich's to the effect that one of the salts of *para*-tartaric acid gave rise to crystals of precisely the same type as the corresponding tartrates. When Pasteur investigated this anomaly he found that, contrary to all previous experience, hemihedral facets appeared on the crystals of the optically inactive *para*-tartrate as well as of its dextro-rotatory isomer. Further examination of this anomaly showed, however, that whereas in the dextro-rotatory tartrate the hemihedral facets were always of one kind, in the *para*-tartrate both types of crystals were formed side by side from the same solution. It appeared, therefore, that when this particular salt was crystallized the *para*-tartaric acid resolved itself spontaneously into two opposite forms of tartaric acid, one of which had been known for nearly a century, whilst the other, its mirror image, was new to science. It is of interest to notice that in no other known case does this spontaneous resolution of an inactive tartrate take place, and that even the two sodium ammonium salts unite to form a double salt above 26° C. It is, therefore, quite possible that Pasteur's life work might have taken a totally different course if he had begun his work in a tropical instead of in a temperate climate.



a *b*

FIG. 2.—(*a*) Dextro-tartaric acid; (*b*) Lævo-tartaric acid.

Pasteur was a young student at the time when he made this important discovery, and, before communicating the results to the Academy, Biot insisted that Pasteur must come to him and repeat before his own eyes the decisive experiment. "He provided me," says Pasteur, "with some *para*-tartaric acid, which he had already studied with particular care and which he had found to be perfectly neutral towards polarized light. I prepared the double salt in his presence, using for the purpose soda and ammonia, which he had also wished to provide for me himself. The liquor was left in one of his rooms to evaporate slowly, and, when it had furnished 30 or 40 grm. of crystals, Biot asked me to

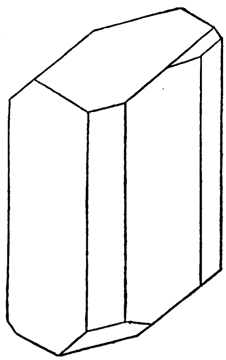


FIG. 3.—Racemic acid.

come to the Collège de France in order to collect them and to separate them under his eyes by their crystallographic character into right and left crystals. He also asked me to state again whether I could assert that the crystals which I placed to his right would rotate the plane of polarization to the right and the others to the left. That done, he told me that he would do the rest. He prepared the solutions of carefully regulated strengths, and, at the moment when he was about to observe them in the polarimeter, he invited me afresh to come into his room. He placed in the apparatus first the most interesting solution, that which would rotate the light to the left. Without stopping even to make a measurement, he saw, by a single glance at the colours of the ordinary and extraordinary images in the analyser, that there was a strong deviation to the left. Then, visibly moved, the illustrious old man grasped my arm and said to me, 'Mon cher enfant, j'ai tant aimé les sciences dans ma vie que cela me fait battre le cœur.'"

The optical rotatory power of quartz is due, as Fresnel had suggested, to a spiral packing of the molecules, and by the kindness of Sir William Bragg I am able to exhibit a model in which the spiral distribution of the atoms of silicon is clearly shown. This spiral structure can be built up in two opposite ways, but when it is destroyed (for example, by melting the quartz) the optical rotatory power vanishes. The asymmetry, then, is in the crystal, but not in the molecules of silica from which it is built up. Tartaric acid, however, displays its optical activity in solution, and we owe to Pasteur the momentous declaration that the *molecules* of tartaric acid, as well as the crystals, must be asymmetric. Here, again, through the kindness of Sir William Bragg, I can show you a model which illustrates both the spiral arrangement of the carbon atoms in tartaric acid and the way in which these spiral molecules are packed together in an asymmetric crystal.

Just a word in reference to the biological applications of these discoveries. Pasteur called attention to the fact that in the mineral kingdom, and by the artificial operations of the chemical laboratory, asymmetric molecules are always produced in equal quantities of opposite types, giving rise to optically inactive compounds or mixtures. Nature, however, almost invariably produces optically active products; and all the materials of the living tissue are branded with this symbol of their divine origin. This, then, is the real distinction between the organic and the inorganic, between nature and man, and this "middle wall of partition" Pasteur was the first to break down. It is indeed a remarkable fact that the three methods which to-day enable us to accomplish the final stage in the synthesis of natural compounds, by endowing our synthetic products with optical activity, were all described by Pasteur more than sixty years ago.

One other link between Pasteur's delicate chemical studies and biology may be mentioned. The mould which ferments ordinary tartaric acid has but little action upon its optical isomer. It was therefore possible by fermenting *para*-tartaric acid to destroy the common dextro-rotatory form, whilst preserving the lævo-rotatory isomer. The yeast, trained for countless generations to assimilate dextro-tartaric acid, refuses to ferment lævo-tartaric acid, and turns away with loathing from the unaccustomed food. This phenomenon has been widely extended, and applies not only to humble organisms but to man himself. Thus, whilst one form of asparagin tastes sweet in the mouth, the mirror image has an insipid taste. If, therefore, through some freak of nature the asymmetry of the vegetable kingdom were reversed, whilst leaving that of the animal kingdom unchanged, we too, like the yeast, might starve in the midst of plenty, unable to digest the unaccustomed sugar with its facets at the wrong corners, or to nourish ourselves upon the finest wheat flour containing starch and gluten of the wrong sign.

This, surely, is the real tragedy of "Alice through the Looking-Glass." The buns and cakes beyond the mirror would present a tempting appearance; the toffee and the barley sugar would still attract her; but if she should stretch out greedy hands and grasp them through the mirror, she would be doomed to disappointment. The fats she would be able to digest, and it might still be necessary to warn her to leave the wine decanter alone, since the alcohol has a symmetrical molecule, and would be equally potent from whichever side of the mirror it was derived; but the carbohydrates and proteins would probably "turn to ashes" in her mouth and provide her with little or no nourishment. Even if she should succeed, however, in finding sufficient food, her growth would certainly be arrested by lack of optically active vitamins of the right sign, and death would certainly await her, perhaps the more merciful if not long delayed. Would insulin be of any value to her in the terrible state into which she would inevitably lapse as a result of wandering to the wrong side of the looking-glass? Even the seven happy years that I spent at Guy's have not qualified me to attempt a prognosis, even when as in this case my diagnosis must be accepted as correct. But, greatly daring, I will assert that all the efforts of the Medical Research Council would fail to save Alice, for the remedies that they would prepare on this side of the looking-glass would have no potency in enabling her to assimilate the strange food on the other side of the glass. Alice must begin all over again, and beyond the mirror organize a medical research council of her own. We should recognize them easily, for the wise inhabitants of that other world would know that they could not do better than to reflect "our" choice, and confirm "our" nomination (I speak on behalf of all the inhabitants, both fauna and flora, of our side of the mirror). But they would have some strange habits. Their hair would be parted on the wrong side; they would carry their watches in their right-hand pockets and listen to the beating of hearts on the right side of their patients. In their moments of leisure they would play golf with clubs of an unfamiliar type, with which they would make magnificent left-hand drives; but their handicaps and their feelings would remain the same, since these things are not altered by reflection in a mirror. They would then manufacture from materials gathered on the other side, suitable and potent remedies for the diseases of that other world; and they would apply these to Alice. At last she would look forward to a cure, but only to meet with fresh disappointment, since the cure would prove to be only a treatment of her disease; for after all Alice herself must undergo optical inversion, limb by limb and molecule by molecule, turning her right hand into a left and reversing the sign of her tissues, as her body passed through the plane of the mirror, before she could fit harmoniously into the framework of the universe beyond. And there at last we may leave her, happy and contented, and enjoying all the good things that life "through the looking-glass" has to offer.

Such, briefly, is the concept which Pasteur places before us as his earliest contribution to natural knowledge; and we cannot but admire the perfect fashioning of the foundation stone upon which in his riper years he built up the splendid monument, which generations still unborn will visit, in order to lay before it a tribute of laurel leaves such as we bear in our hands to-night.